CEMENTING VALUE OF BITUMINOUS BINDERS

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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THE CEMENTING VALUE OF BITUMINOUS BINDERS.

A THESIS

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PREFACE.

The subject of THE CEMENTING VALUE OF BITUMINOUS BINDERS as herein presented is not an attempt to treat all the bituminous binders used in asphalt pavements, but the ones which are at present of a great commercial importance, the so-called PAVEMENT STANDARDS.

The various materials examined were classified according to their origin and use, into four groups. The first group contains asphalt cements prepared from SOLID NATURAL BITUMENS: 1. Trinidad, 2. Bermudez, 3. Gilsonite; the second includes asphalt cements prepared from OIL RESIDUUM: 1. Standard Oil, California, Star Brand, 2. Montezuma, Mexico, Warner Quinlan Co.; the third includes products made from BLOWN OILS: 1. Blown California, Low Duck, Union Oil Co., 2. Blown Kansas, Sarco; and the fourth includes the fluxes used: 1. Whiting, 19°-21° Be., paraffine base, 2. Gulf, 12°-14° Be., Texas heavy semi-asphaltic, 3. Sun, 18° Be., Texas light semi-asphaltic, 4. Monarch, California, asphaltic base.

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THE CEMENTING VALUE OF BITUMINOUS BINDERS.

INTRODUCTION.

The modern asphalt pavement in its perfected state is the evolution of forty years of experiment and experience. A short history of the origin of this form of pavement on the Continent of Europe and in the United States will not be out of place here.

Asphalt paving in this country may be said to date from the year 1870, although there were a few pieces laid before this date. The first regular asphalt pavements in Europe were laid in Paris in 1856 and in London in 1869 in which limestone rock asphalts were employed.

The success of these pavements in Europe attracted considerable attention in this country, but the great expense of shipping and laying the European asphalts prevented their use excepting in one or two experimental pieces. Attempts, however, were made to use coal-tar mixed with mineral ingredients. In 1867 several coal-tar pavements

were laid, the great majority of which were utter failures, while some few have given and are still givingexcellent service at the present date. With the paucity of knowledge of the constuction and of the materials used in such paving at that time, it is little wonder that there were so many failures, and it can be considered merely accidentalthat any of thesefirst still remain.

In 1870 Edward J. De Smedt procured patents for the manufacture of pavements, using Trinidad asphalt softened by heavy petroleum oil and mixed with sand and powdered lime. Samples of this new pavement proved very satisfactory.

In 1892 Thomas H. Thomas obtained a grant of land at Guanoco, province of Bermudez, Venezuela, for mining asphalt. This deposit is generally known on the market as the Bermudez asphalt. He commenced the laying of pavement with this asphalt fluxed with petroleum residuum, and so successfully competed with the Trinidad Lake Interests that it was bought up by the latter.

In Uinta county, Utah, a pure, hard asphalt, gilsonite, has been mined for a number of years,

but it was not until 1898 that its use was commenced for paving. This asphalt was fluxed with heavy California maltha until a proper consistency for a paving cement.

Besides the natural asphalts, there have been used for paving artificial asphalts manufactured from oils, known as fluxes. In 1894 a patent was procured for the manufacture of an artificial asphalt from petroleum by the oxidationof petroleum residuum by blowing air into it while heated at a high temperature.

The first successful effort to place the industry on a rational basis, as distinguished from the rule-of-thumb methods previously in vogue, was made in 1894; and especially during the past ten years has there been a great development in the methods of valuating paving bitumens.The earlier attempts at determining these values were directed towards chemical determinations of properties or constituents which were thought to have an influence upon the quality of materials of this kind. Later developments have indicated that, with few exceptions, the valuable properties of paving materials are in-

cluded more directly in their physical characteristics. The present status of the determination of paving values includes physical tests as the more important ones, leaving a few chemical tests directed towards determining the permanency of these products, and the care with which they have been prepared.

THE GENERAL PROBLEM.

It will be generally agreed that the most important, if not primary physical property, which paving bitumens must posses is that of cementitiousness. For a long time efforts have been directed towards devising a means of measuring the cementing value, but so far nothing has been offered in this direction which has met with general approval. Among the tests commonly employed, that of ductility has been assumed to measure or to be, in a general way, an indication of cementitiousness. While possibly there is some relationship between ductility and the cementing value of a given type of bitumen, it will be admitted that no mathematically direct relationship, if any, exists at all. So far, then, as our present means of determining cementing values are concerned, this most important feature must be arrived at, by indirect interpretation of data which affords no exact means of determining such values.

The problem now was to establisha satis-

factory method for directly and matematically expressing the cementing value of plastic binders; and having done this to make a series of investigations covering the following points:-

(1) Survey of the characteristics of commercial products with special reference to determining the degree of differentiation possible with the various materials.

(2) The possibility of valuating fluxes by this method.

(3) The determination of standards of value necessary for practical application.

DESCRIPTION AND ANALYSIS OF MATERIALS USED.

In order to obtain complete information of the characteristics of the materials employed a short description and analysis of each will be given below.

(1) Trinidad asphalt is the bitumen best known in the United States, and its use for street pavement has been colossal. Of the fifty million square yards of asphalt pavement in the United States 85% is of a mixture in which Trinidad asphalt was used. The average properties of the refind Trinidad Lake asphalt used are as follows:

Physical Properties.

Specific gravity at 77°F.	1.40
Color of powder	Blue-black
Lustre	Dull
Structure	Homogeneous
Fracture	Semi-conchoidal
Odor	Asphaltic
Softens	180°F.
Flows	190°F.
Penetration at 77°F.	70

Chemical Characteristics.

Soluble in CS_2, air temp. ---- 56.4%

Organic matter insoluble ----- 6.7

Inorganic or mineral matter -- 36.9 100.0

Loss, 325°F., 7 hours -------- 1.1%

Fixed carbon ----------10.8%

Ultimate Composition.

C ---------- 82.59%

H ---------- 10.74

S ---------- 6.04

N ---------- .51 99.88

(2) Bermudez asphalt is a comparatively pure bitumen and consequently possesses the lustre of such material instead of the dull fracture of Trinidad bitumen which is due to the presence of mineral matter. It has a uniform structure with here and there small particles of vegetable organic matter. It is most variable in composition, material from different parts of the deposit showing great lack of uniformity in both its physical and chemical properties. The average properties of the refined Bermudez asphalt are as follows:

Physical Properties.

Specific gravity at 77°F. ---- 1.08

Color of powder ---------- Black

Lustre ---------- Bright

Structure ---------- Uniform

Fracture ---------- Semi-conchoidal

Odor ---------- Asphaltic

Softens ---------- 170°F.

Flows ---------- 180°F.

Penetration at 77°F. --------- 22°

Chemical Characteristics.

Soluble in CS_2, air temp. ---- 95.0%

Organic matter insoluble ----- 2.5

Inorganic or mineral matter -- 2.5 100.0

Loss, 325°F., 7 hours -------- 3.0

Fixed carbon ---------- 13.4%

Ultimate Composition.

C ---------- 82.88%

H ---------- 10.79

S ---------- 5.87

N ---------- .75 100.29%

(3) Gilsonite is the purest native bitumen with which we are acquainted, the best varieties containing 99.5% of bitumen, but with traces of

inorganic and organic matter not of a bituminous nature. It is readily soluble in the heavy asphaltic residue from California and Texas petroleums and, when mixed with this in the proper proportion, makes a material which is extremely rubbery and more or less elastic. The average properties are as follows:

Physical Properties.

Specific gravity at 77°F.	1.04
Color of powder	Red-brown
Lustre	Lustrous
Structure	Uniform
Fracture	Conchoidal
Odor	None
Softens	265°F
Flows	305°F
Penetration at 77°F.	0°

Chemical Characteristics.

Bitumen soluble in CS_2, air temp.--	99.4%	
Organic matter insoluble	.3	
Inorganic or mineral matter	.3	100.0%
Loss, 325°F., 7 hours	.43	
Fixed Carbon	14.5	

Ultimate Composition.

C	89.28%	
H	8.66	
S	1.79	
N	1.79	100.52%

(4&5) All petroleums on evaporation under suitable conditions leave a pitchy residue. The residue from the asphaltic or semi-asphaltic petroleums resembles the native asphalts. The principle supplies available for use in the paving industry are residual pitches from Cal., Texas, and Mexico oils. These can be readily differentiated by certain characteristics especially by the percentage of fixed carbon. The average analysis of the oils residuums used runs as follows:

Physical Properties.

	Standard Oil	Montezuma
Specific gravity	1.002	1.043
Melting point	122°F.	138°F.
Flash point	515°F.	475°F.
Penetration at 77°F.	50°	59°
Ductility at 77°F.	115 cms.	115 cms.

Chemical Characteristics.

	Standard Oil		Montezuma	
Soluble in CS_2, air temp.	99.6%		99.7%	
Organic matter insoluble	.3		.1	
Mineral matter	.1	100%	.2	100%
Loss, 325°F., 7 hours	.2%		.4%	
Fixed Carbon	9.3%		14.2%	

(6&7) The blown oils or oxidized petroleum residues are characterized by their lack of susceptibility to temperature changes but have extremely low ductility, which prevents their use as the main source of bitumen in the paving mixture. However excellent asphalt cements have been prepared for paving purposes to which additions of blown oil, not exceeding 10% in amount, have been made. While the materials constituting these additions are in themselves unsuitable for paving purposes, they seem to modify the properties of native bitumen in such a way as to improve them. The average analysis of the blown oils used runs as follows:

	Low Duck	Sarco
Physical Properties.		
Specific gravity	1.02	.991
Melting point	150°F.	203°F.
Flash point	450°F.	500°F.
Penetration at 77°F.	43°	34°
Ductility at 77°F.	100 cms.	4 cms.
Chemical Characteristics.		
Soluble in CS_2, air temp.	99.7%	99.0%
Organic matter insoluble	.1	.6
Mineral matter	.2	.4
	100.0%	100.0%
Loss, 7 hours, 325°F.	1.5%	.5%
Fixed carbon	.14%	11.3%

(8-11) In order to bring the solid native bitumens to such a consistency as will make them available for use as a paving cement it is generally necessary to flux them with some other softer bitumen. The flux in use for this purpose is a heavy residuum prepared by the removal of the lighter portions of petroleum by distillation. These residues naturally vary in character in the same way that the petroleums do from which they have been derived. The fluxes now in use in the

paving industry may be considered as consisting of three classes: paraffine petroleum fluxes, asphaltic petroleum fluxes, semi-asphaltic fluxes. Their properties run as follows:

	Whiting	Sun	Gulf	Monarch
Physical Properties.				
Specific gravity	.93	.9459	.979	.9908
Flash point	425°F.	350°F.	465°F.	330°F.
Chemical Characteristics.				
Soluble CS_2	99.8%	99.8%	99.6%	99.9%
Insoluble	.2	.2	.4	.1
	100%	100%	100%	100%
Fixed carbon	3%	3%	3%	6%
Loss, 7 hours,	1.2%	4%	.4%	5%
Paraffine scale	7.9%	1%	1.7%	none

Under microscope all are free from coke.

THE CEMENTING VALUE MACHINE AND ITS USE.

The chief apparatus employed in this work and which need be described are the Cementing Value Machine and the Dow Penetration Machine. The other apparatus are ordinary Physico-Chemical laboratory apparatus and need not be described here.

The Cementing Value Machine was devised and designed by Mr. L. Kirshbraun of the Chicago Paving Laboratory. It records two factors, strain applied over distance, the product of which is work done. As the binding or cementing value is directly proportional to the work done in producing fracture of a given unit of materialthis machine is then a means for direct measurement of cementitiousness. The apparatus in its final form is shown in figures 1 and 2. It consists of a rectengular box insulated or lined with galvanized iron. An inclined plane or runway is attached to the box, the lower end of which reaches the bottom of the box, and the other end projects an equal distance outside.

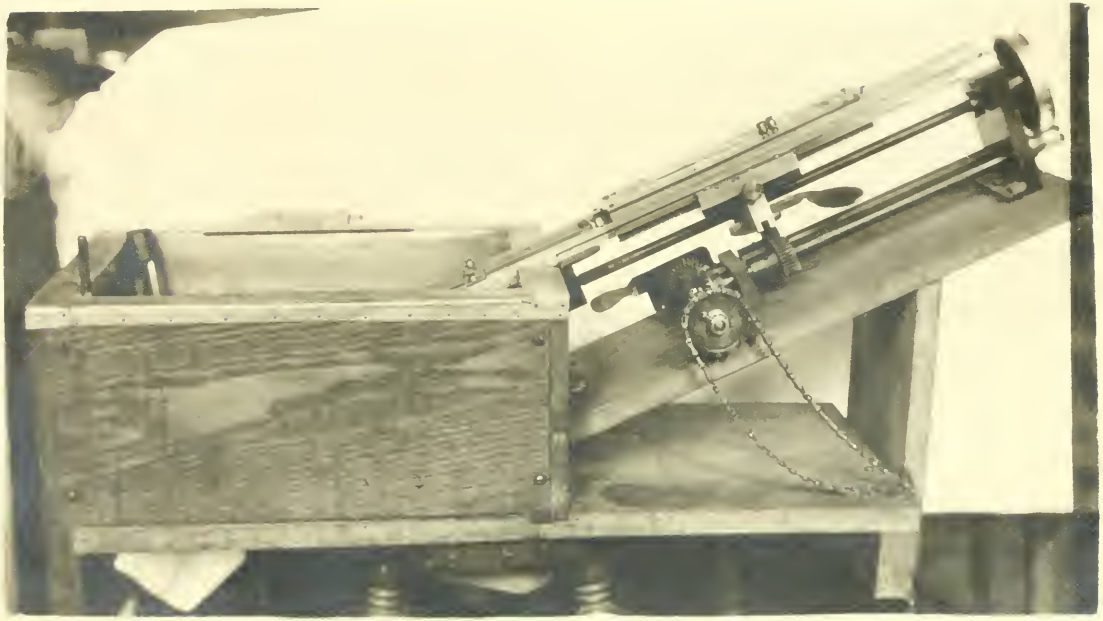

Figure 1. (page 19)

Figure 2.

This runway carries a carriage through which passes a screw actuated by a set of gears adjustable to the desired speed. Upon the carriage is maintained a dynamometer, to the end of which is connected a flat brass rod, which extends along the runway to within a few centimeters of the end and the bottom of the boss.This rod is graduated in metric units, and passes under an adjustable bridge at which the readings are recorded during travel of the rod. The runway is edged with guides of sufficient width for the free passage of the briquettes. The arrangement and position of the carriage makes it possible to apply a tension through the rod in a straight line to briquettes at the lower end of the runway with the box filled with water. At the lower end of the runway is permanently fastened a small boss or projection to which one end of the briquette is attached, the other end being attached to the rod connected with the dynamometer. The position of the bridge gives readings of elongation of the briquette regardless of the movement of the carriage and dynamometer. The form of briquette adopted is that commonly known as the Dow moulds

which are used for making ductility tests. These moulds have a minimum cross section of 1 sq.cm.

In working out the method of manipulation, it was necessary to determine a constant temperature at which the test should be made. The temperature selected was 5°C. or 41°F. This was selected for several reasons. In the first place it was necessary to obtain sufficiently large readings upon the dynamometer. At normal temperatures, bituminous materials of this kind are ordinarily capable of withstanding very little strain. Secondly, the strains which produce fracture and cracking in a pavement in actual service are greatest during cold weather. Again a low temperature being necessary, the temperature of 5°C. was selected as being easy to maintain constantly with ice and water.

On account of the plastic nature of the material operated upon, and its tendency to elongate under strain, it was necessary to determine upon a uniform means of application of load. It was evidently impossible to set a uniformly increasing load for the reason that as the material elongated, and its cross-section became smaller, it would be necessary to rapidly accelerate the rate of elongation or travel of the

dynamometer towards the end of the operation, in order to increase the strain. This would become impracticable as a matter of manipulation, and would be subject to large variation through personal equation and through inability to take the required readings sufficiently rapidly. It was found necessary after many trials to adopt a uniform rate of travel of carriage and dynamometer. This is in accord with practical conditions in as much as any strain set up in a pavement would be induced at a variable rate of application depending on the ability of various binders to yield or elongate without fracture.

Various trials were made at different speeds in order to determine what speed was most adapted in securing concordant results, and in distinguishing to the greatest degree, the difference between various materials. Speeds between 1 to 10 cms. per minute were tried upon the same materials. It was found that the higher speeds had a tendency to effect too sudden application of strain, and, with the harder materials,to produce fracture in the corner of the briquettes rather than at the point of minimum cross-section. Again, at the

faster speeds, it became difficult to take the readings near the time of fracture owing to the rapid travel of the rod and the pointer of the dynamometer. After various trials it was found that a speed of travel of the carriage and dynamometer at the rate of 1 cm. per minute provided to the greatest extent for the factors indicated above. It will be understood that in applying strain to the briquette by means of a dynamometer travelling at a uniform speed, the briquette has at first a slight tendency to elongate under the application of strain, until a maximum is reached, when the rate of elongation of the briquette exceeds the rate of travel of the carriage and dynamometer at which points the dynamometer begins to register value below the maximum attained until finally the briquette is either fractured at a reduced cross-section, or the dynamometer returns to zero without fracture of the briquette.

In making the test, as finally adopted, the briquettes are prepared in the usual manner as for a ductility test, and are placed in the test box at 5°C. They are held for about three-quarters

of an hour at this temperature before making the test. When ready, one end of the briquette is hitched to the fixed post at the bottom of the box on the runway, and the dynamometer brought into position so that the end of the rod attached to same may be fastened to the other end of the briquette. The apparatus is driven mechanically, and the carriage is started by closing the split-nut which brings it into contact with the screw. When the pointer of the dynamometer begins to move over its zero mark, the bridge over the rod is adjusted to the zero mark on the rod. The carriage and the dynamometer continue to travel at the rate of 1 cm. per minute, and readings of the dynamometer are taken at every half centimeter of elongation shown by the rod. This is continued until the briquette fractures or elongates through its maximum back to zero strain. The dynamometer carries a maximum pointer and is graduated in tenths of kilogram, and the zero mark is taken as one-tenth kilogram which includes the weight of the briquette and the frictional resistance of parts. The position of the rod and boss are such as to lift the

briquette slightly off the runway when the strain is applied so that no friction results during the application of strain. Figure 3 illustates the positions of the briquette and the dynamometer at various stages of the test.

The results of the data obtained in these determinations may be graphically recorded. The distances elongated are recorded as abscissae, and the strain as ordinates. Plate I gives a typical example of results obtained upon the same material at different consistencies under this method of test. The areas enclosed by these curves represent the product of the strain applied and the distance of its application, or the work done. The unit of value is expressed as kilogram meters. This area may be obtained from the graphical plot of the result, or may be secured much more quickly, and sufficiently accurately, by the addition of the ordinates. The readings are taken for every .5 cm. or .005 of a meter. Every unit of ordinate, therefore, represents .005 kilogram meters, and the sum of the ordinates multiplied by this factor gives the area or the work done in kilogram meters.

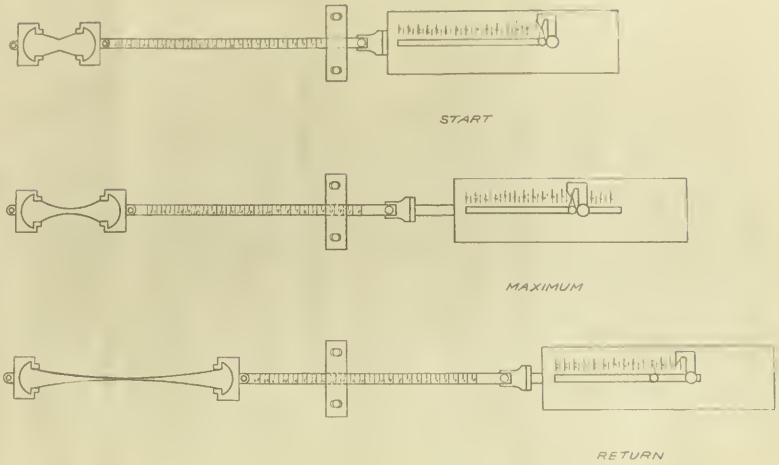

FIGURE 3.— POSITIONS OF DYNAMOMETER AND BRIQUETTE DURING TEST

Expressed mathematically, the formula for calculating the result is $\leq Yx.005$. This is sufficiently accurate for practical purposes. Reffering again to plate I, it will be noted that the same material at different consistencies requires widely varying amounts for failure. With the harder materials a comparatively sharp curve is obtained with a certain maximum, and then becomes less as the material elongates faster than the carriage travels. When the cross-section is reduced to a point at which it is unable to withstand the strain induced, it breaks. With the materials of the softer consistency there is a tendency of the curve to flatten and to become longer as the material is more plastic. A consistency is finally reached at which the material is able to progress through to its maximum strain and back to zero (or .1 kilogram) without fracture. All tests were obtained in duplicate, and the results indicate a limit of accuracy of .02 kilogram meter from an average on the highest results, to a much closer agreement upon the lower values. Exception to this accuracy is noted upon the hard brittle materials which are unable to elongate uniformly without setting up internal strain due to the corners of the briquette.

THE DOW PENETRATION MACHINE AND ITS USE.

The Dow Penetration Machine, Fig. 4, is based on the measurement of the millimeters to which a standard needle penetrates into the asphalt cement under a definite weight at a definite temperature.

The object of the penetration test is to ascertain the consistency of asphalts, and is accomplished by determining the distance a weighted needle will penetrate into the specimens under examination.

So that all tests may be comparable, a standard needle is used weighted with a constant weight. The tests are made on samples at a standard temperature and are made for the same length of time. The standards used in this machine for testing cements are a #2 needle, weighted with 100 gms., penetrating for 5 seconds into the sample at a temperature of 77°F. (25°C.).

The apparatus consists of a #2 needle A, inserted in a short brass rod which is held in the aluminum rod C by the binding screw B. The aluminum rod is secured in a framework so weighted and balanced that when it is supported on the point of the needle A the framework and rod will

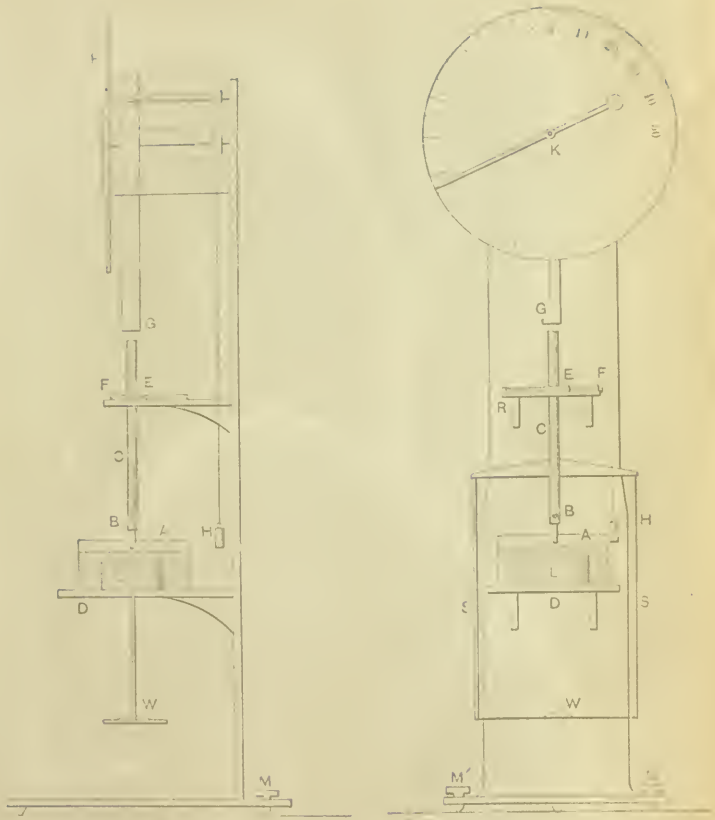

FIG. 4—Dow Penetration Machine.

(page 27)

stand in an upright position, allowing the needle to penetrate perpendicularly without the aid of a support, thus doing away with any friction.

The frame, aluminum rod, and needle weigh 100 gms. with the weight on bottom of frame, without weight 50 gms. Thus when the point of the needle rests on the surface of the sample of material to be tested, it will penetrate into the sample under a weight of 100 gms. or 50 gms. as desired.

D is the shelf for the sample, E is the clamp to hold the aluminum rod C until it is desired to make a test, F is a button which when pressed opens clamp E. By turning this button while the clamp is being held open it will lock and keep the clamp from closing until unlocked. The device to measure the distance penetrated by the needle consists of a rack, the foot of which is G. The movement of this rack up or down turns a pinion to which is attached the hand which indicates on dial K the distance moved by the rack. One division of the dial corresponds to 1/100 Cm. The rack

can be raised or lowered by moving counter-weight H up or down. L is a tin box containing sample to be tested which is covered with water in a dish-pan, thus keeping its temperature constant. MM' are leveling screws.

The only other things necessary to complete the outfit are a metronome, a large dishpan, a pitcher to hold ice-water and a tin for hot water.

To make penetration tests the materials contained in circular tins are placed under five or six inches of water in the dish-pan, which should have been previously brought to a temperature of 77°F. by addition of hot or cold water.

While the samples are under the water it should be stirred every few minutes, with the thermometer and the temperature kept constant at 77°F. The samples should remain under the water for at least one-half hour.

The aluminum rod C is pressed up through the clamp E so that it will be at such a height that the tin box will easily pass under it when placed on shelf D. A sample in tin box is placed on shelf D under C. Brass rod with needle is inserted into C and secured by tightening binding screw B,

C is lowered until the point of the needle is just in contact with surface of sample.

After thus settling the needle, counter-weight H is slowly raised until the foot of the rack G rests on the head of rod C; reading on dial is noted, thumb of right hand is placed on R and button F is pressed with forefinger, thus opening the clamp. It is held open for five seconds and then closed. The difference between the former reading of the dial and the present is the distance penetrated by the needle, or the penetration of the sample. The rack and rod are now raised, the needle cleaned by passing through a dry cloth,and the machine is ready for another test.

ASPHALT TESTS.

In order to obtain complete information of the characteristics of commercial products, it was necessary to collect such data as would represent a wide range of consistency for each material. The refined asphalt was accordingly used and fluxed with the kind of flux ordinarily used in practice. Determinations were made upon each material at a number of different consistencies and these values were graphically expressed as abscissae and the consistencies as ordinates. The various materials examined were classified into three groups according to their origin. Record was made of the cementing value as determined by the data presented, together with the elongation and the maximum strain sustained. These data are given below in tables 1, 3 and 5, and their summaries for plotting curves in tables 2, 4 and 6.

NOTE: In the following tables numbers with ° stand for penetrations; numbers with ( ) stand for true elongations; numbers with * stand for cementing values.

GROUP I.

TABLE I.

ASPHALT "A" AND FLUX1"1".

Cms.	Kilograms.					
	37°	46°	50°	59°	72°	82°
0.5	3.5-3.9	2.5-2.5	2.3-2.4	1.6-1.6	1.3-1.3	1.2-1.3
1.0	4.9-5.3	3.4-3.5	3.2-3.4	2.3-2.3	1.9-1.8	1.7-1.8
1.5	5.7-6.0	3.9-4.1	3.7-3.9	2.6-2.7	2.2-2.1	1.9-2.0
2.0	6.1-6.4	4.3-4.4	4.0-4.2	2.8-2.9	2.3-2.2	2.0-2.1
2.5	6.3-6.5	4.4-4.5	4.1-4.4	2.8-2.9	2.3-2.3	2.0-2.1
3.0	6.3-6.4	4.5-4.4	4.2-4.4	2.8-2.9	2.3-2.3	2.0-2.1
3.5	6.0-6.0	4.4-4.2	4.2-4.3	2.7-2.9	2.2-2.2	2.0-2.0
4.0	(3.5-3.5)	4.2-3.9	4.2-4.1	2.4-2.7	2.0-2.1	1.8-1.9
4.5	*.194-.202	3.9-3.7	4.2-3.8	2.2-2.5	1.8-1.9	1.6-1.7

Cms.	Kilograms.					
	37°	46°	50°	59°	72°	82°
5.0		3.7-	3.8-	1.6-2.2	1.4-1.7	1.4-1.5
5.5		(4.8-4.3)	3.4-	-2.3	1.2-1.4	1.2-1.2
6.0		*.197-.172	3.0-	-1.5	.8-1.2	.9- .9
6.5			(6.0-4.5)	-1.1	.5- .8	.7- .7
7.0			*.315-.186	(5.0-6.5)	- .4	.4- .3
7.5				*.119-.152	- .2	.3- .2
8.0					(6.5-7.5)	.2-
8.5					*.111-.125	.1-
						(8.5-7.5)
						*.107-.109

ASPHALT "B" AND FLUX "L".

Cms.	Kilograms.						
	11°	22°	41°	45°	51°	64°	80°
.5	7.9-7.2	4.4-4.5	2.5-2.3	2.1-2.1	1.7-1.7	1.5-1.5	1.0-1.0
1.0	(.2- .25)	6.5-6.0	3.6-3.4	2.9-2.9	2.4-2.4	2.1-1.8	1.3-1.2
1.5	*.016-.018	7.3-6.9	4.3-4.0	3.5-3.5	2.9-2.9	2.4-2.1	1.5-1.4
2.0		(1.4-1.5)	4.7-4.4	3.8-3.8	3.2-3.2	2.5-2.3	1.6-1.5
2.5		*.087-.087	5.0-4.7	4.0-4.0	3.5-3.4	2.6-2.4	1.6-1.5
3.0			5.1-4.9	4.2-4.2	3.6-3.5	2.5-2.4	1.6-1.5
3.5			5.1-5.0	4.3-4.3	3.7-3.6	2.5-2.4	1.6-1.5
4.0			5.1-5.0	4.3-4.3	3.8-3.6	2.5-2.4	1.6-1.5
4.5			5.0-5.0	4.3-4.3	3.8-3.6	2.4-2.3	1.5-1.4
5.0			4.9-5.0	4.2-4.2	3.7-3.4	2.2-2.2	1.4-1.3
5.5			4.5-4.9	4.0-3.9	3.6-3.3	2.0-2.0	1.3-1.2
6.0			4.0-4.7	3.8-3.7	3.5-3.1	1.7-1.9	1.2-1.1

Cms.	Kilograms.						
	11°	22°	41°	4.5°	51°	64°	80°
6.5			-4.4	3.4-3.3	3.3-2.8	1.4-1.7	1.1-1.0
7.0			-4.0	3.0-2.8	3.0-2.4	1.0-1.5	.9- .9
7.5			(6.0-7.0)	(7.0-7.2)	2.7-2.0	.8-1.3	.8- .7
8.0			*.269-.308	*.259-.357	2.4-1.7	.4-1.0	.7- .6
8.5					2.0-	.2- .8	.5- .5
9.0					1.6-	.1- .6	.4- .4
9.5					1.3-	- .4	.3- .3
10.0					(9.5-8.0)	- .3	.2- .25
10.5					*.278-.233	-.2	.2- .25
11.0						-.1	.2- .2
11.5						(9.0-11.0)	.15-.15
12.0						*.154-.168	.1 -.1
							(12.0-12.0)
							*.114-.106

ASPHALT "C" AND FLUX "3".

Cms.	Kilograms.		
	34°	55°	81°
.5	2.3 - 2.3	1.3 - 1.2	.8 - .8
1.0	3.5 - 3.5	1.8 - 1.7	1.1 - 1.1
1.5	4.2 - 4.3	2.3 - 2.1	1.2 - 1.4
2.0	4.8 - 4.9	2.4 - 2.3	1.3 - 1.5
2.5	5.1 - 5.4	2.5 - 2.4	1.3 - 1.5
3.0	5.4 - 5.8	2.6 - 2.6	1.3 - 1.5
3.5	5.5 - 5.9	2.7 - 2.6	1.3 - 1.5
4.0	5.6 - 6.1	2.7 - 2.6	1.3 - 1.5
4.5	5.7 - 6.3	2.7 - 2.6	1.3 - 1.5
5.0	5.8 - 6.4	2.6 - 2.6	1.3 - 1.5
5.5	5.8 - 6.5	2.5 - 2.5	1.2 - 1.5
6.0	5.8 - 6.4	2.4 - 2.4	1.2 - 1.4
6.5	5.4 - 6.2	2.2 - 2.1	1.1 - 1.3
7.0	- 5.9	2.1 - 2.0	1.0 - 1.2
7.5	(6.5 - 7.0)	1.9 - 1.8	.9 - 1.1
8.0	*.325 - .379	1.4 - 1.4	.8 - ..9
9.0		.7 - .6	.5 - .6
10.0		(9.0 - 9.0)	.3 - .3
11.0		*.191 - .185	.2 - .2
12.0			.1 - .1
			(11.5-12.0)
			*.105 - .121

TABLE II. PLATE II.

ASPHALT "A" AND FLUX "1".

Pen. @ 77° F.	Max. Strain.	Cementing Value.	Elongation Cms.
37	6.4	.198	3.5
46	4.5	.185	4.6
50	4.3	.201	5.25
59	2.85	.136	5.75
72	2.3	.118	7.0
82	2.05	.108	8.0

ASPHALT "B" AND FLUX "1".

11	6.8	.017	.22
22	7.1	.087	1.2
41	5.05	.288	6.5
45	4.33	.268	7.1
51	3.7	.255	8.75
64	2.5	.161	10.0
80	1.55	.111	12.0

ASPHALT "C" AND FLUX "3".

34	6.15	.352	6.75
55	2.65	.188	9.0
81	1.4	.113	11.75

GROUP II.

TABLE III.

ASPHALT "D" AND FLUX "4".

Cms.	Kilograms.							
	30°	43°	54°	63°	72°	83°	91°	134°
0.5	6.4-6.8	4.5-4.5	3.4-3.3	2.9-2.6	2.5-2.5	1.9-1.8	1.8-1.4	.9-1.0
1.0	9.0-9.3	6.3-6.2	4.5-4.5	3.7-3.5	3.2-3.4	2.4-2.3	2.3-2.0	1.1-1.2
1.5	10.7-10.9	7.4-7.3	5.2-5.1	4.3-4.1	3.6-3.9	2.7-2.6	2.6-2.2	1.2-1.3
2.0	11.9-11.9	8.2-8.0	5.7-5.6	4.6-4.4	3.8-4.1	2.8-2.7	2.7-2.4	1.2-1.3
2.5	12.7-12.8	8.8-8.6	6.0-6.0	4.9-4.6	3.9-4.2	2.9-2.8	2.7-2.5	1.2-1.3
3.0	13.5-13.4	9.3-9.0	6.3-6.2	4.9-4.75	4.0-4.3	2.9-2.8	2.8-2.5	1.2-1.3
3.5	13.7-13.6	9.6-9.3	6.5-6.3	5.0-4.8	4.0-4.3	2.9-2.8	2.7-2.5	1.2-1.3
4.0	(3.2-3.5)	9.8-9.5	6.6-6.4	5.0-4.8	4.0-4.3	2.9-2.8	2.6-2.5	1.2-1.2
4.5	*.369-.393	9.8-9.6	6.6-6.4	5.0-4.8	3.9-4.2	2.8-2.7	2.5-2.4	1.1-1.1
5.0		10.0-9.6	6.6-6.4	4.9-4.7	3.8-4.1	2.6-2.6	2.4-2.3	1.0-1.0
5.5		10.1-9.6	6.5-6.3	4.8-4.55	3.7-4.0	2.5-2.5	2.2-2.3	.9- .9

Cms.	Kilograms.							
	30°	43°	54°	63°	72°	83°	91°	1344
6.0		-9.5	6.4-6.2	4.75-4.4	3.5-3.9	2.4-2.3	2.1-2.1	.8-.8
6.5		(5.5-6.4)	6.3-6.0	4.5 -4.15	3.3-3.6	2.2-2.3	1.9-2.0	.7-.8
7.0		*.469-.503	6.1-5.8	4.3 -3.9	3.1-3.5	2.0-2.1	1.7-1.9	.7-.7
7.5			5.8-5.5	4.0 -3.6	2.9-3.2	1.9-1.9	1.5-1.75	.6-.6
8.0			5.5-	3.8 -3.3	2.6-3.0	1.7-1.8	1.4-1.6	.5-.5
8.5			(8.0-7.7)	3.5 -2.8	2.4-2.7	1.5-1.6	1.2-1.5	.5-.5
9.0			*.479-.430	3.1 -2.6	2.1-2.4	1.4-1.5	1.1-1.4	.4-.4
9.5				2.9 -	1.8-2.1	1.2-1.4	1.0-1.2	.4-.4
10.0				(9.5 -9.0)	1.5-1.7	1.0-1.2	.8-1.15	.4-.4
10.5				*.401-.389	1.3-1.4	.9-1.1	.7-1.0	.3-.35
11.0					1.1-1.0	.8-1.0	.6- .9	.3-.3
11.5					.9-	.6- .8	.6- .8	.3-.3
12.0					.5-	.5- .7	.5- .75	.3-.3
12.5					.4-	.4- .7	.4- .65	.2-.2

Cms.	Kilograms.							
	30°	43°	54°	63°	72°	83°	91°	134°
13.0					.3-	.4- .5	.3- .55	.2- .2
13.5					.2-	.3- .5	.3- .5	.2- .2
14.0					.2-	.3- .4	.3- .4	.2- .2
14.5					.2-	.2- .4	.2- .4	.2- .2
15.0					.1-	.2- .3	.2- .35	.2- .15
15.5					(15.0-11.0)	.2- .3	.2- .3	.2- .1
16.0					*.343-.364	.2- .3	.2- .25	.1-
16.5						.2- .25	.2- .2	(16.05.5)
17.0						.2- .2	.1- .15	*.099-.103
17.5						.2- .2	- .15	
18.0						.1- .15	- .15	
18.5						- .1	- .1	
						(18.0-18.5)	(17.-18.5)	
						*.251-.263	*.224-.234	

ASPHALT "E" AND FLUX "E".

Cms.	Kilograms					
	41°	53°	61°	69°	80°	136°
.5	1.9 - 1.9	1.3 - 1.5	1.2 - 1.2	1.2 - 1.0	.9 - 1.0	.15- .15
1.0	2.6 - 2.7	2.0 - 2.1	1.6- 1.5	1.5 - 1.4	1.2 - 1.3	.2 - .2
1.5	3.1 - 3.2	2.4 - 2.5	1.9 - 1.8	1.7 - 1.5	1.3 - 1.5	.25- .25
2.0	3.4 - 3.6	2.6 - 2.7	2.1 - 2.0	1.8 - 1.6	1.4 - 1.5	.3 - .3
2.5	3.6 - 3.9	2.7 - 2.8	2.2 - 2.1	1.8 - 1.7	1.4 - 1.5	.3 - .3
3.0	3.8 - 4.0	2.8 - 2.9	2.2 - 2.1	1.8 - 1.7	1.4 - 1.5	.3 - .3
3.5	3.8 - 4.1	2.8 - 2.9	2.2 - 2.1	1.8 - 1.7	1.4 - 1.5	.3 - .3
4.0	3.8 - 4.1	2.8 - 2.8	2.2 - 2.1	1.8 - 1.7	1.4 - 1.5	.3 - .3
4.5	3.8 - 4.1	2.7 - 2.7	2.2 - 2.0	1.8 - 1.6	1.3 - 1.4	.3 - .3
5.0	3.6 - 4.0	2.5 - 2.5	1.9 - 1.9	1.7 - 1.5	1.2 - 1.3	.3 - .3
5.5	3.3 - 3.7	2.4 - 2.2	1.8 - 1.8	1.5 - 1.4	1.1 - 1.2	.3 - .3
6.0	3.0 - 3.7	2.0 - 1.8	1.6 - 1.7	1.4 - 1.1	1.0 - 1.1	.3 - .3
6.5	2.5 - 3.1	1.7 - 1.3	1.4 - 1.4	1.3 - .9	.8 - 1.0	.3 - .3

Cms.	41°	53°	61°	69°	80°	136°
7.0	2.0 -	1.3 - .9	1.0 - 1.1	1.0 - .7	.7 - .8	.3 - .3
7.5	(7.0-- 6.5)	.9 -	.8 - .9	.9 - .5	.5 - .7	.3 - .25
8.0	*.221 - .229	(7.5 - 7.2)	.4 - .5	.7 - .3	.4 - .5	.3 - .25
8.5		*.165 - .168	.3 - .3	.5 - .2	.3 - .4	.3 - .25
9.0			.2 - .2	.3 - .2	.3 - .3	.3 - .25
9.5			.1 - .1	.2 - .15	.2 - .3	.3 - .2
10.0			(9.5 - 9.5)	.2 - .15	.2 - .2	.25- .2
10.5			*.137 - .134	.15- .1	.15- .2	.2 - .15
11.0				.1 -	.1 - .15	.2 - .15
12.0				(11.0 - 10.5)	- .15	.2 - .15
13.0				*.124 - .105	(11.0 -12.0)	.15- .15
14.0					*.093 -.103	.15- .1
14.5						.1
						(14.5 -14.0)
						*.036-.033

TABLE IV. PLATE III.

ASPHALT "D" AND FLUX "4".

Pen. @ 77° F.	Max. Strain.	Cementing Value.	Elongation Cms.
30	13.65	.383	3.3
43	9.75	.486	5.95
54	6.5	.450	7.85
63	4.9	.395	9.25
72	4.15	.353	13.0
83	2.85	.257	18.25
91	2.62	.229	18.5
134	1.25	.101	15.75

ASPHALT "E" AND FLUX "E".

41	3.95	.225	6.75
53	2.85	.162	7.35
61	2.15	.136	9.5
69	1.75	.115	10.75
80	1.45	.098	11.5
136	.3	.035	14.25

GROUP III.

TABLE V.

ASPHALT "F" AND FLUX "F".

Cms.	Kilograms.				
	31°	40°	55°	70°	97°
.5	2.4 - 2.8	2.0 - 2.0	1.3 - 1.2	.8 - .8	.6 - .6
1.0	3.7 - 4.0	2.7 - 2.8	1.9 - 1.7	1.0 - 1.1	.8 - .8
1.5	4.4 - 4.8	3.1 - 3.3	2.2 - 1.9	1.2 - 1.3	.9 - .9
2.0	4.9 - 5.3	3.4 - 3.6	2.4 - 2.1	1.3 - 1.4	.9 - .9
2.5	5.2 - 5.7	3.6 - 3.8	2.5 - 2.2	1.3 - 1.4	.9 - .9
3.0	5.4 - 5.9	3.8 - 3.9	2.6 - 2.2	1.3 - 1.4	.9 - .9
3.5	5.5 - 6.0	3.8 - 3.9	2.6 - 2.2	1.3 - 1.4	.9 - .9
4.0	5.5 - 6.0	3.8 - 3.9	2.6 - 2.3	1.3 - 1.4	.9 - .9
4.5	5.5 - 6.0	3.8 - 3.8	2.6 - 2.2	1.3 - 1.4	.9 - .9
5.0	5.3 - 5.8	3.6 - 3.6	2.5 - 2.2	1.3 - 1.4	.9 - .9
5.5	4.8 - 5.5	3.4 - 3.2	2.4 - 2.0	1.3 - 1.4	.9 - .9

Cms.	31°	40°	55°	70°	97°
6.0	(5.5 - 5.3)	2.9 - 2.6	2.2 - 1.8	1.3 - 1.3	.8 - .8
6.5	*.263 - .284	2.7 -	1.9 - 1.5	1.2 - 1.2	.8 - .8
7.0		(6.8 - 6.2)	1.6 - 1.2	1.1 - 1.1	.7 - .7
7.5		*.213 - .202	1.2 - .8	1.0 - 1.0	.7 - .7
8.0			.8 - ..6	.9 - .9	.6 - .6
8.5			.1 - .1	.8 - .7	.6 - .6
9.0			(8.5 - 8.5)	.7 - .6	.5 - .5
10.0			*.167 - .141	.4 - .3	.4 - .4
11.0				.2 - .2	.4 - .3
12.0				.15- .1	.3 - .2
13.0				.1	.2 - .2
14.0				(12.5-12.0)	.2 - .15
15.0				*.112 - .113	.1 - .1
					(15.0-14.5)
					*.088 - .086

ASPHALT "G" AND FLUX "G".

Cms.	Kilogramms.			
	37°	65°	100°	118°
.5	3.5-3.3	2.1-2.2	1.0-1.1	.8 - .9
1.0	4.3-4.3	2.5-2.7	1.2-1.2	.8 -1.0
1.5	4.0-4.2	2.4-2.7	1.2-1.2	.8 - .9
2.0	(1.5-1.5)	2.0-2.3	1.0- .8	.4 - .5
2.5	*.059-.059	(2.0-2.0)	.5- .3	.1 - .1
		*.045-.050	(2.5-2.5)	(2.5-2.5)
			*.025-.023	*.015-.017

TABLE VI. PLATE IV.

ASPHALT "F" AND FLUX "F".

Pen. @ 77° F.	Max. Strain.	Cementing Value.	Elongation Cms.
31	5.75	.273	5.4
40	3.85	.208	6.5
55	2.4	.154	8.5
70	1.35	.112	12.25
97	.9	.087	14.75

ASPHALT "G" AND FLUX "G".

37	4.3	.059	1.5
65	2.6	.047	2.0
100	1.2	.024	2.5
118	.9	.016	2.5

DISCUSSION OF RESULTS.

Group I contains asphalt cements prepared from solid natural bitumens, and groups II and III include products made from natural liquid bitumens.

Results obtained are given graphically in plates II, III, and IV. It was found desirable to plot elongation in order to complete the means of interpretation of results: the graphical presentation of these data indicates a relationship between consistency and cementing value on one hand, and consistency and elongation on the other. Referring to plates it is possible to compare the values of any of the materials at the same penetration. It will be noted that the cementing value increases generally as the consistency becomes harder, but when a certain hardness is reached, there appears to be a breaking off in the value determined in this way, owing to the brittleness and the inability of the material to yield without internal strains induced by the form of the briquettes. This is a factor dependentupon the speed of the

pull, and in all likelihood, there would be a continuation of the curves beyond the present points at a slower rate of pull. Such procedure, however, would minimize the differences between these materials at those consistencies at which such differences are of greatest importance.

The increasing of binding value with hardness and the increase of elongation with softness is quite in accord with practical observations. For example, if a material be laid under light traffic at, say, 65 penetration, experience has shown us that we must reduce the penetration under heavy traffic, in order that the mineral particles may be bound together more solidly to resist impact and displacement. On the other hand, when we lay a pavement at 65 penetration for light traffic, we require greater ability in the material to elongate in order to resist cracking than we do under heavy traffic. This is true because heavy traffic tends to knead the pavement, and relieve the stresses set up by changes of temperature. It will be noted that the cementing value is not directly proportionate to the elongation, and that in some cases, the binding value of two different

materials at the same penetration is very similar, whereas their ability to elongate at the same penetration is appreciably different. Likewise,particularly at the lower penetrations, some materials elongate to practically the same extent, yet their cementing values are widely different. It is evident from the study of these graphical data that it is not only necessary to consider the elongation as a factor in the cementing value, but it is also necessary to consider it apart from the cementing value. If this was not so, our pavements would be less liable to crack when laid at the harder consistencies. It appears therefore, that while the cementing value indicates the ability of the material to bind aggregate together, a minimum ability to elongate is also necessary to avoid cracking. It will further be noticed that the general tendency of the elongation curves is to straighten upward beyound a certain consistency, and in some cases even to retreat. This indicates that beyound a certain amount, fluxing not only results in less binding value, but results in reduced ability to elongate, and that nothing should be gained, so far as plasticity is con-

cerned, by further fluxing. In the case of material "G", there would hardly be any consistency at which the material might be handled which would overcome the tendency to crack. This in a practical way has been actually found to be the case. Attention may be called, at this point, to the fact that various materials showing the same maximum strain possess widely different cementing values. For example, asphalt "E" at 53 penetrationshows 2.85 kg. maximum strain. The same value is shown by asphalt "D" at 83 penetration, yet the cementing of this latter greatly exceeds that of asphalt "E". This is a typical example which indicates the ability of this testto differentiate beyound any ordinary tension test.

FLUX TESTS.

Tables VII and VIII are given showing the results of investigations made in the effort to determine the possibility of valuating various fluxes. In this series of tests the same asphalt was used throughout, and was fluxed with different fluxes, the cementing values and other data being determined as indicated before.

TABLE VII.

ASPHALT "C" AND FLUX "1".

Cms.	Kilogramms.			
	45°	53°	76°	88°
.5	2.1-2.0	1.3-1.5	1.0-1.0	.8 - .8
1.0	3.0-3.0	2.0-2.0	1.5-1.5	1.2 -1.2
1.5	3.6-3.6	2.4-2.5	1.7-1.8	1.4 -1.4
2.0	3.8-4.0	2.7-2.8	1.9-2.0	1.6 -1.6
2.5	3.9-4.0	2.9-3.0	2.0-2.1	1.7 -1.7
3.0	(2.5-2.3)	3.0-3.1	2.1-2.1	1.7 -1.7
3.5	*.082-.083	3.0-3.1	2.1-2.1	1.7 -1.7
4.0		3.0-3.1	2.0-2.0	1.7 -1.6
4.5		2.6-2.9	1.8-1.8	1.5 -1.4
5.0		-2.5	1.5-1.5	1.2 -1.1
5.5		-2.2	.9-1.0	.9 - .8
		(4.6-5.5)	(5.5-5.5)	(5.5-5.5)
		*.115-.144	*.093-.095	*.072-.075

ASPHALT "C" AND FLUX "2".

Cms.	Kilogramms.			
	30°	44°	68°	83°
.5	1.7-1.8	1.2-1.3	.6- .7	.6- .5
1.0	2.6-2.6	1.8-1.9	.9-1.0	.8- .8
1.5	3.1-3.2	2.2-2.3	1.1-1.2	1.0- .9
2.0	3.5-3.6	2.5-2.5	1.3-1.4	1.1-1.0
2.5	3.7-3.8	2.7-2.8	1.4-1.5	1.2-1.1
3.0	3.8-3.9	2.8-2.9	1.5-1.5	1.211.1
3.5	3.9	2.9-3.0	1.5-1.5	1.2-1.2
4.0	(3.0-3.7)	3.0-3.0	1.5-1.5	1.2-1.1
4.5	*.092-.114	3.0-3.0	1.5-1.5	1.2-1.1
5.0		3.0-3.0	1.5-1.5	1.2-1.1
5.5		3.0-2.6	1.5-1.5	1.2-1.1
6.0		2.8-	1.5-1.4	1.1- .9
6.5		2.6-	1.3-1.3	.9- .7
7.0		2.2-	1.0-1.0	.7- .4
7.5		1.9-	.7- .5	.4- .3
8.0		(7.4-5.5)	.3- .2	.2- .15
8.5		*.188-.141	(8.2-8.0)	.1- .1
			*.096-.096	(8.5-8.5)
				*.077-.067

ASPHALT "C" AND FLUX "3".

Cms.	Kilograms.		
	34°	55°	81°
.5	2.3 - 2.3	1.3 - 1.2	.8 - .8
1.0	3.5 - 3.5	1.8 - 1.7	1.1 -1.1
1.5	4.2 - 4.3	2.2 - 2.1	1.2 -1.4
2.0	4.8 - 4.9	2.4 - 2.3	1.3 -1.5
2.5	5.1 - 5.4	2.5 - 2.4	1.3 -1.5
3.0	5.4 - 5.8	2.6 - 2.6	1.3 -1.5
3.5	5.5 - 5.9	2.7 - 2.6	1.3 -1.5
4.0	5.6 - 6.1	2.7 - 2.6	1.3 -1.5
4.5	5.7 - 6.3	2.7 - 2.6	1.3 -1.5
5.0	5.8 - 6.4	2.7 - 2.6	1.3 -1.5
5.5	5.8 - 6.4	2.6 - 2.6	1.2 -1.5
6.0	5.8 - 6.5	2.5 - 2.5	1.2 -1.4

Cms.	Kilograms.		
	34°	55°	81°
6.5	5.4 - 6.2	2.4 - 2.4	1.1 - 1.3
7.0	- 5.9	2.2 - 2.1	1.0 - 1.2
7.5	(6.5 - 7.0)	1.9 - 1.8	.9 - 1.1
8.0	*.324 - .379	1.4 - 1.4	.8 - .8
8.5		1.0 - .9	.7 - .8
9.0		.7 - .6	.5 - .7
9.5		(9.0 - 9.0)	.4 - .5
10.0		*.191 - .185	.3 - .3
10.5			.2 - .2
11.0			.2 - .2
11.5			.1 - .2
12.0			- .1
			(11.5-12.0)
			*.105 - .121

ASPHALT "C" AND FLUX "4".

Cms.	Kilograms.					
	35°	45°	51°	59°	79°	130°
.5	2.6 - 2.5	2.0 - 1.9	1.8 - 1.9	1.4 - 1.4	.9 - .8	.3 - .3
1.0	3.8 - 3.6	2.7 - 2.6	2.5 - 2.6	1.9 - 1.9	1.2 - 1.0	.4 - .4
1.5	4.5 - 4.4	3.2 - 3.2	3.0 - 3.0	2.2 - 2.2	1.3 - 1.1	.4 - .4
2.0	5.0 - 4.9	3.5 - 3.5	3.3 - 3.3	2.4 - 2.4	1.4 - 1.3	.4 - .4
2.5	5.4 - 5.3	3.8 - 3.8	3.4 - 3.4	2.5 - 2.5	1.4 - 1.3	.4 - .4
3.0	5.6 - 5.5	3.9 - 4.0	3.5 - 3.5	2.6 - 2.6	1.4 - 1.3	.4 - .4
3.5	5.8 - 5.7	4.0 - 4.1	3.6 - 3.6	2.7 - 2.6	1.4 - 1.3	.4 - .4
4.0	5.9 - 5.8	4.1 - 4.2	3.6 - 3.6	2.7 - 2.6	1.4 - 1.3	.4 - .4
4.5	6.0 - 5.8	4.1 - 4.2	3.6 - 3.6	2.7 - 2.6	1.4 - 1.3	.4 - .4
5.0	5.9 - 5.8	4.1 - 4.2	3.6 - 3.5	2.7 - 2.6	1.3 - 1.3	.4 - .4
5.5	5.8 -	4.1 - 4.2	3.4 - 3.3	2.7 - 2.4	1.3 - 1.3	.4 - .4
6.0	(5.5 - 5.0)	4.0 - 4.1	3.3 - 3.2	2.7 - 2.3	1.2 - 1.2	.4 - .4
6.5	*.282 - .246	3.9 - 4.0	3.0 - 2.9	2.6 - 2.2	1.2 - 1.2	.4 - .4

Cms.	35°	45°	51°	59°	79°	130°
7.0		3.7 - 3.9	2.8 - 2.6	2.5 - 2.1	1.1 - 1.1	.35 - .35
7.5		3.5 - 3.7	2.5 - 2.2	2.4 - 1.9	1.0 - 1.1	.3 - .3
8.0		3.2 - 3.5	2.0 - 1.8	2.2 - 1.7	.9 - 1.0	.3 - .3
8.5		2.8 - 3.2	1.8 - 1.7	2.1 - 1.2	.8 - .9	.3 - .3
9.0		2.5 - 2.8	(8.5 - 8.5)	1.9 - 1.0	.7 - .8	.3 - .3
9.5		(8.8 - 8.5)	*.254 - .249	1.7 - .7	.6 - .7	.3 - .3
10.0		*.316 - .327		1.4 - .4	.5 - .6	.25 - .25
10.5				1.2 - .2	.4 - .6	.25 - .25
11.0				.9 - .1	.3 - .5	.2 - .2
12.0				.3	.2 - .4	.2 - .2
13.0				.1	.1 - .25	.15 - .15
14.0				(13.0-11.0)	.15	.1 - .1
				*.246 - .198	.1	(14.0-14.0)
					(13.0-14.5)	*.043 - .043
					*.119 - .125	

TABLE VIII. PLATE V.

ASPHALT "C" AND FLUX "1".

Pen. @ 77° F.	Max. Strain.	Cementing Value.	Elongation Cms.
45	3.95	.083	2.4
53	3.05	.130	5.0
76	2.1	.094	5.5
88	1.7	.074	5.5
	ASPHALT "C" AND FLUX "2".		
39	3.85	.103	3.35
44	3.0	.165	6.45
68	1.5	.096	8.1
83	1.15	.072	8.5
	ASPHALT "C" AND FLUX "3".		
34	6.15	.352	6.75
55	2.65	.188	9.0
81	1.4	.113	11.75
	ASPHALT "C" AND FLUX "4".		
35	5.9	.264	5.25
45	4.15	.322	8.9
51	3.6	.252	8.5
59	2.65	.222	12.0
79	1.35	.122	13.75
130	.4	.043	14.0

DISCUSSION OF RESULTS.

Results obtained are given graphically in plate V. It will be noted that the cementing values of these materials are progressively greater as the fluxes tend towards asphaltic base, with this exception that the paraffine combinationshows slightly better values than the light semi-asphaltic. This is due to the fact that much less paraffine base flux was used to produce the consistencies noted, than in the case of the light semi-asphaltic flux. When, however, the elongation curves are examined, a progressive increase without exception is noted in ability to elongate as the fluxes used partake more of an asphaltic character. It will be noted that the ability to elongate would become even a more sensitive indication of the character of the flux itself than the cementing value. The practical necessity for considering this ability to elongate is aptly illustrated here. The above asphalt used with paraffine flux has proven unsatisfactory in practice. Under light traffic, pavements laid

with this have shown sufficient binding qualities to hold the mineral particles together, but the tendency to crack is very decided. On the other hand, this asphalt with light semi-asphaltic flux has shown in a practical way, that the cracking tendency is greatly reduced in laying at a sufficiently high penetration, and it has been much more satisfactory than the previous combination even though its cementing value is not greater. The materials with the asphaltic and the heavy semi-asphaltic fluxes have been eminently successful under service conditions. It is evident from the above that the method described furnishes a means of determining the value of various fluxes and their suitability in asphalt combinations.

DETERMINATION OF CEMENTING VALUE STANDARDS.

In the preceding discussion, various commercial asphalts which have been used in paving work have been examined. It remains, therefore, to analyze the data obtained in connection with practical results and to determine,if possible, from such analysis, what cementing characteristics appear to be necessary for the successful use of these kinds of binders.

From the information received by the writer from Mr. Lester Kirshbraun, an authority on the subject, it may be stated broadly that unsuccessful results have been observed with materials R.A. + Paraffine flux, and "G", while with the other materials successful pavements have been laid. To what extent, then, these groups of materials differ in their cementing value characteristics becomes a matter of practical importance in determining acceptable values. The lowest cementing observed with a material which has given satisfactory results in practice under light traffic is .08

kilogram meter given by R.A. + light semi-asphaltic flux at 80 penetration. The highest cementing value possessed by a material which has an unsatisfactory service record (R.A. + Paraffine flux) is.10 kilogram meter. The difference here, between successful and unsuccessful use does not reside in the cementing values alone, but also in the ability of the material to elongate. Both materials possessing the two values referred to are able to bind the mineral particles in a sheet asphalt pavement together sufficiently well to endure light traffic. In the one case, however, the material is prone to crack, while the other case represents practically the lowest safe limit at which the cracking tendency is overcome. It would therefore appear that for light traffic, a minimum cementing value might be prescribed of .08 kilogram meter, together with limiting values of elongation between 8 to 14 cms. for the pure bitumen. Above these combined values will fall those materials which have demonstrated satisfactory use under light traffic and below these values will fall those materials

which have been unsatisfactory for the same conditions.

The above applies for conditions generally described as light traffic. Pavements under heavy traffic require more cementitious binders, but less ability in these binders to elongate. From service records of materials laid under heavy traffic calling for a penetration of 35 to 40 with materials of the first group, a minimum cementing value for those materials may be prescribed as .26 kilogram meter and elongation limits of from 5 to 6 cms.

CONCLUSION.

From the foregoing it will be apparent that while the matter of proper consistency is of great importance, it may be predetermined from the above to a considerable degree for any material for given conditions of traffic. For example, if the advisable elongation necessary for heavy traffic be 5 to 6 cms., it will be seen at once, that asphalt "D" (Plate III) should be laid at about 40 penetration, and that it possesses sufficient cementing value at this consistency for the conditions referred to (.486 kilogram meter). On the other hand, considering material "A" (Plate II) we would find the required elongation obtained at 55 penetration, at which consistency the cementing value would be much below the required minimum (.198 kilogram meter) and the material found unsuitable for use for heavy traffic.

ACKNOWLEDGEMENTS.

I desire to acknowledge my indebtedness to Mr. Lester Kirshbraun,B.S., Director of Chicago Paving Laboratory, for the accomodations as well as for his valuable informations and suggestions offered me during the work.

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APPENDIX.

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KEY TO LETTERS.

ASPHALTS.

A. Trinidad.

B. Bermudez.

C. Gilsonite.

D. California, Star Brand.

E. Mexico, Montezuma, Warner Quinlan Co.

F. Blown California, Low Duck.

G. Blown Kansas, Sarco.

R.A. Refined Asphalt.

FLUXES.

1. Whiting, 19°-21° Bé. Paraffine.

2. Sun, 18° Bé, light Semi-asphaltic.

3. Gulf, 12° to 14° Bé, heavy semi-asphaltic.

4. Monarch California, Asphaltic.

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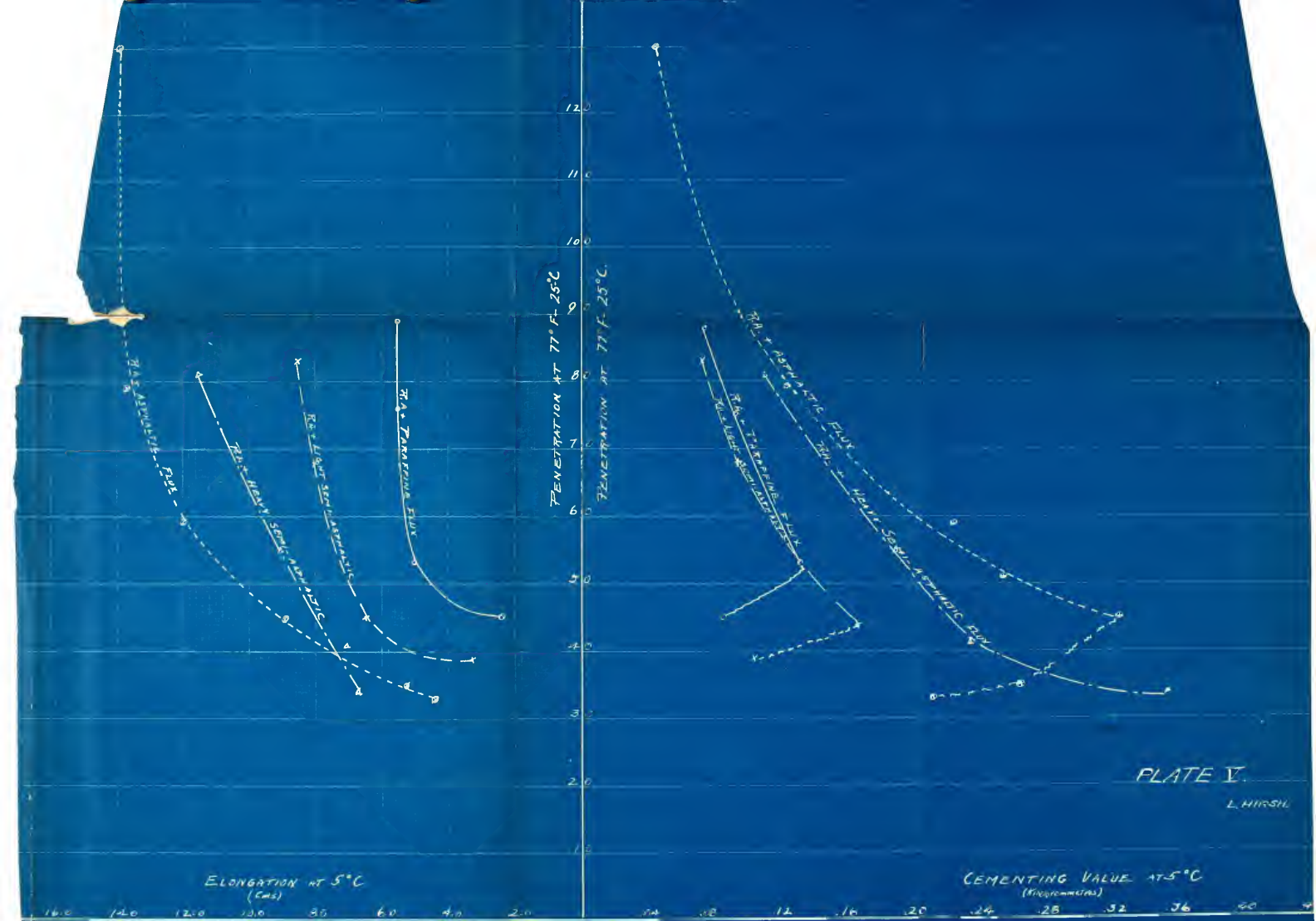


PLATE V.

L. HIRSH.

"Ventfold" CROSS SECTION PAPER. 10 × 10 - 1 INCH
EUGENE DIETZGEN Co.

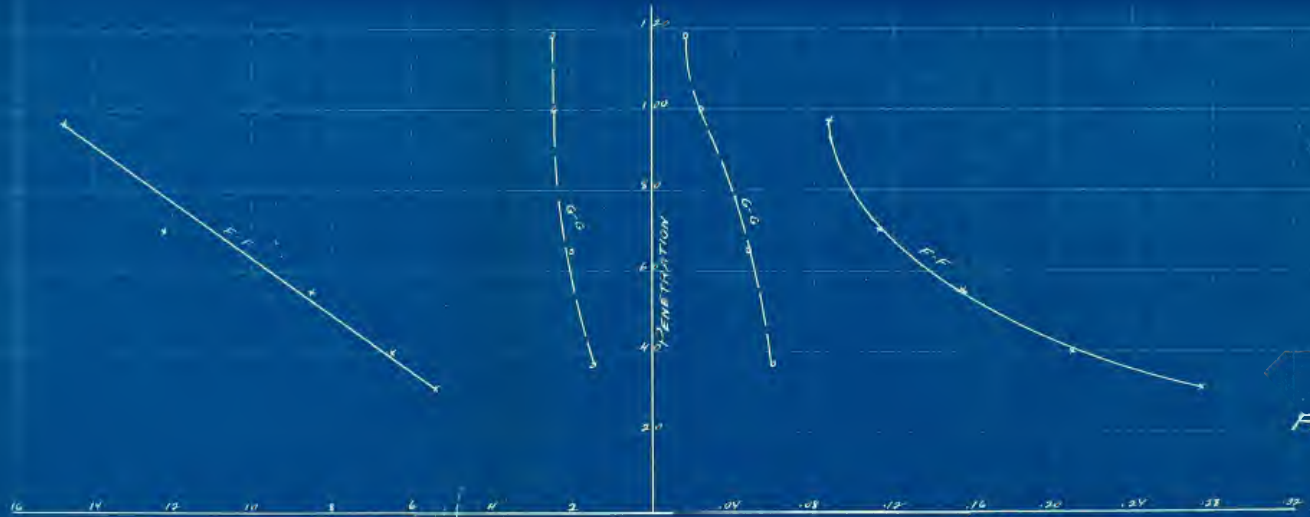
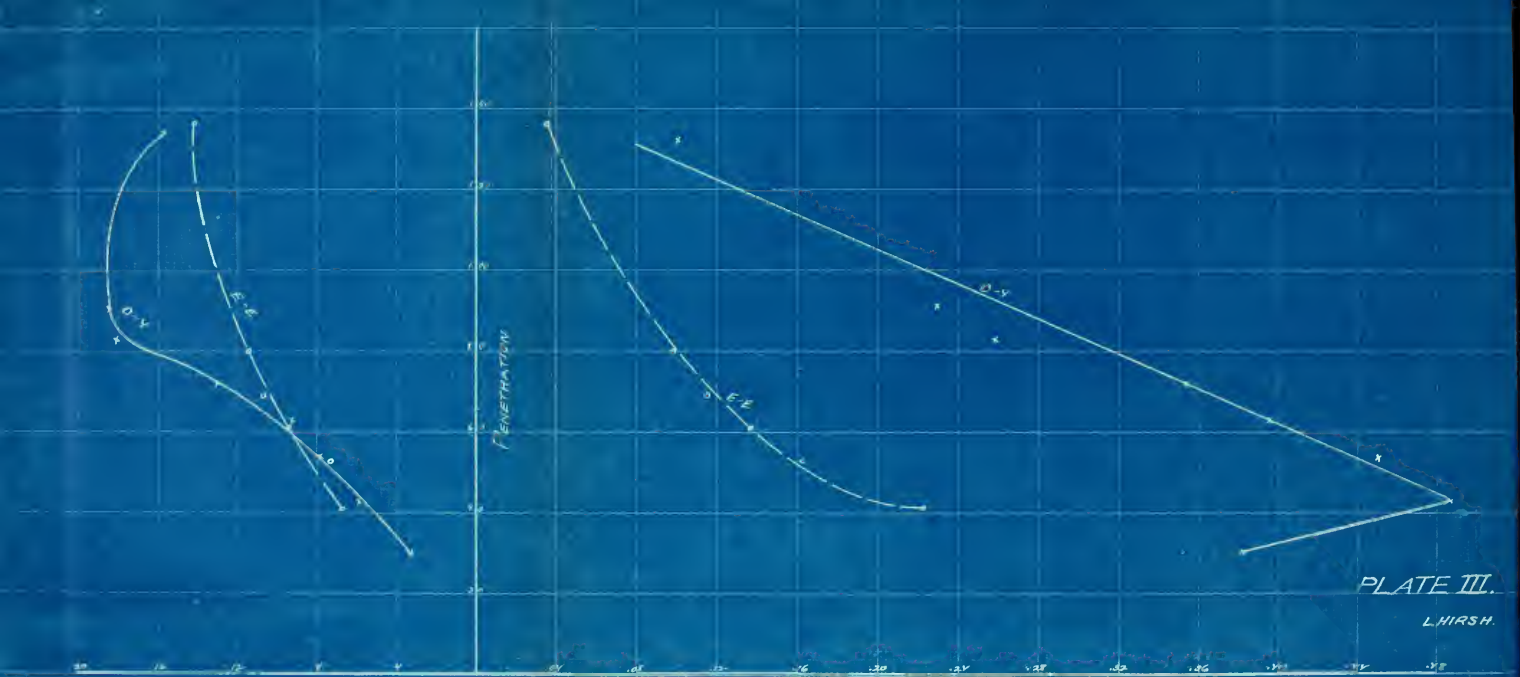


PLATE IV.

L. HIRSH.


D-V
E-E
PENETRATION
D-V
E-E
PLATE III.
L. HIRSH.
Cms. Elongation
Cementing Value, Kilogrammeters.

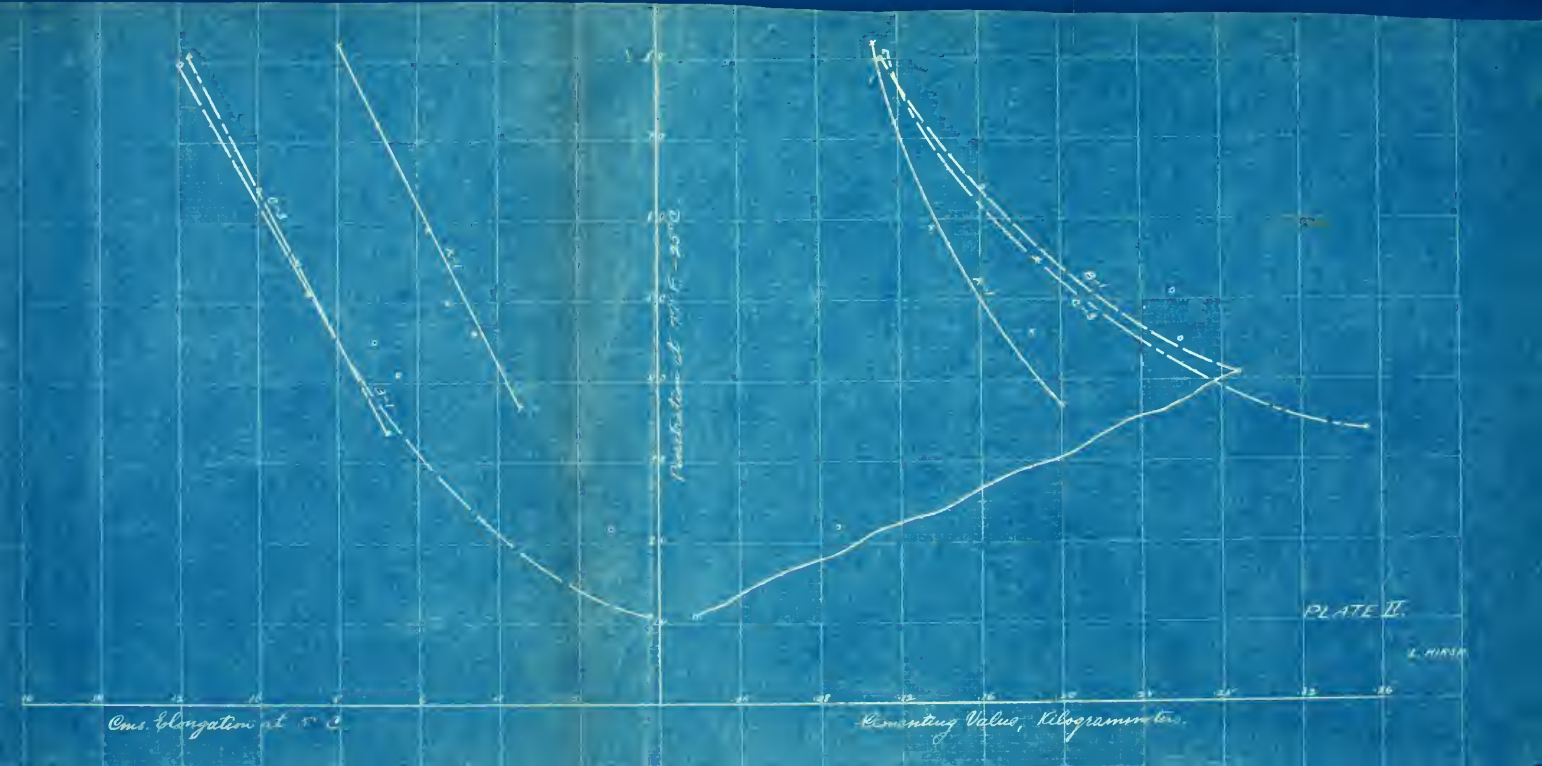


PLATE II.
Cms. Elongation at 5° C.
Remaining Value, Kilogrammeters.

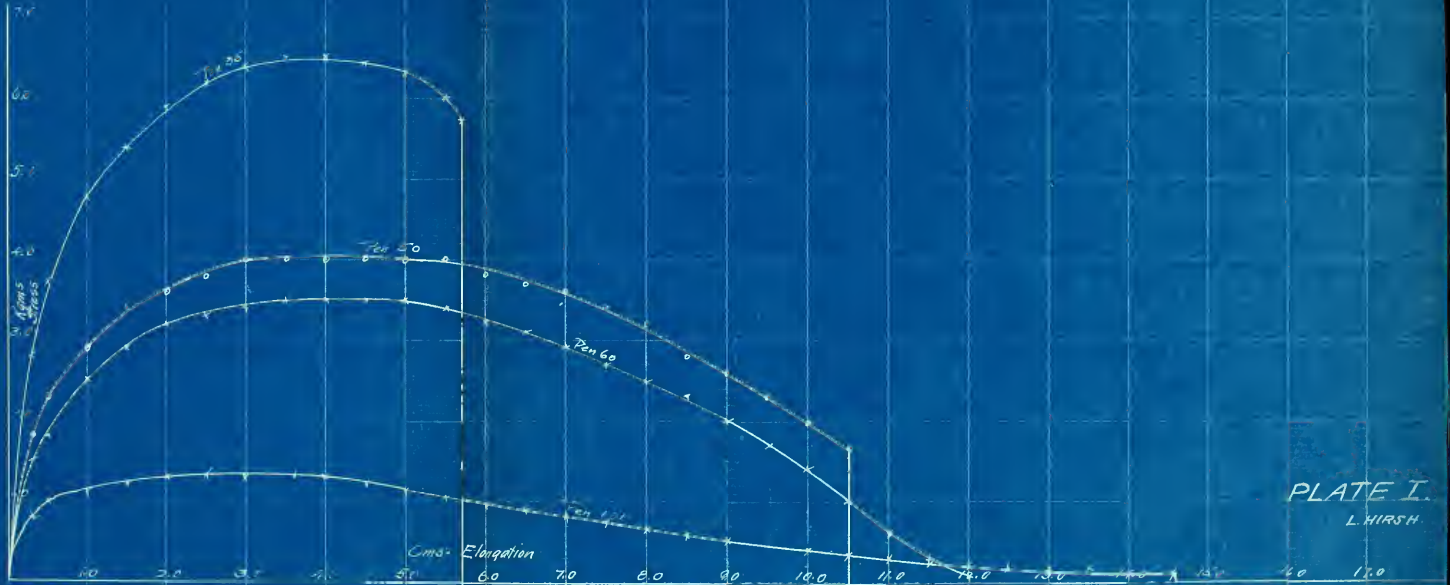


PLATE I.

L. HIRSH.